Application of Statistical Process Control Technique for Evaluating Machine Capability: A Case Study

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Abstract

This paper discusses the use of statistical process control (SPC) for evaluating production machinery capability and efficiency of production machineries in Malaysian manufacturing companies. The case study was conducted at three manufacturing companies' coded names: company A, B and C. In the first part of the case study, the authors had gathered the profile of the three companies', general requirements in quality management, general information about SPC and its application at each company. Having done that, later the authors investigated each company's past experienced in implementing SPC in their production department. First, in Company A the authors had found that the manufacturing processes for making base plates are still in control. In company A, the high speed milling machine used is very capable of producing consistent frame lengths for the base plates because the process capability indexes (C_p = 2.62 and C_{pk} = 2.27), which are more than 1. In company B, the manufacturing process for printed circuit board (PCB) was found to be out of control. In company B, the authors had not studied and calculated its process capability index because the manufacturing process was already out-of-control. In other words, it is already very obvious that the machine used in the manufacturing process for PCB was not capable. Meanwhile company C, which is currently producing compressed pill tablet seems to be in control. However, the study found that the pill tablet compression machine capability index at C_p = 1.16, seems to be capable of producing pill tablets with hardness within the upper and lower control limits. In this case, the process is not centred because C_{pk} = 0.93 is less than 1 and thus the distribution of pill tablets hardness are not following the normal distribution.

***Keywords**: Statistical process control, Process capability, Machine capability, Manufacturing company*

1 Introduction

In a harsh market environment, product or service quality is a very important weapon to enable companies to compete and satisfy their customer requirements. The importance of quality has been long recognised in many organisations for obtaining high quality products. According to Samat *et al*. [1], most organizations in Malaysia have started to use quality as an essential part of their strategies to meet challenges and improve their positions in the market place. Quality in manufacturing requires the practices of statistical process control (SPC) for controlling and managing a process either manufacturing through the use of statistical methods [2]. Ishikawa [3] points out that SPC's strength lies in its ability to monitor both process centre and its variation about that centre. It can be done by collecting data from samples at various points within the process; variations in the process that may affect the quality of end product can be detected and corrected. Thus, SPC will be able to reduce the probability of passing problems to the customers. SPC has a distinct advantage over other quality control techniques, such as final inspection, which utilise human resources for detecting and correcting problems at the end of the production cycle. In other words, SPC emphasize on early detection and prevention of problems. In other words, SPC is aimed at continuously improving the process to manufacture quality product for achieving high customer satisfaction [4].

For over 70 years, the manufacturing disciplines has benefited from the tools of SPC to lead in decision-making process. In essence, control charts and process capability utilized in SPC are proposed to identify the process stability and performance [5]. Utilization of control charts are aimed to identify and to remove variations in processes that exceed the variation to be expected from natural causes [6]. If the chart indicates that the process is currently under control then it can be used with confidence to predict future performance of the process. If the control chart indicates the process being monitored is not in control, the pattern it reveals can be used to determine the source of variation, which needs to be eliminated to bring the process back into control. Salzman [7]; Derelyd [8] and Jagadeesh and Babu [9] agreed that process capability can be used as a means to measure the performance of a machine or process for producing products that meets with the required quality standards. According to them, process capability study can be performed by measuring the actual output of a process and later compare it with the given specifications for the process or product. According to Derelyd [8] capability study is associated with several measures called process capabilities indices that intentionally used to compare the actual process output with the specification limits for certain characteristics.

In the context of this study, to measure or to evaluate machine capability and efficiency, one could be dealing with process capability. In conducting machine capability study, the data set must be homogeneous [8]. For example, data need to be gathered using the same: material, set-up, machine, operator and shift. Moreover, in order to assess process capability either the performance of machine or process, it is necessary to ensure that the process is not influence by any assignable cause or out of control [9]. This paper presents the result of a case study conducted at three manufacturing companies with respect to SPC application to evaluate machine capability and efficiency in Malaysian manufacturing companies. At times, it was very difficult to do because the measuring process involved seeking information, some of which are confidential and companies were not willing to cooperate. Despite several difficulties faced, the authors managed to complete the case studies successfully. Knowledge gained from this study would be invaluable to other manufacturing companies that are planning to improve or implement SPC in their companies.

2 Literature review

SPC is one of the techniques used in quality assurance programs and/or in total quality management, abbreviated as TQM [10]. SPC and TQM are generally associated respectively by each other. TQM is a philosophy to nurture continuous improvement activities in an organization. Meanwhile, SPC is a technique found in TQM, which stresses primarily on satisfying the customers through the adoption of continuous improvement during product manufacturing stage [11].

SPC is a powerful problem-solving technique used for monitoring, controlling, analysing, managing and improving a process using statistical methods. SPC is a type of feedback system in which information about a process is used to maintain and improve the process. The main goal of a SPC system is to make economically efficient decisions concerning the types of actions to take on a process and who should

initiate the action [12]. SPC is a statistical technique commonly used to control processes and reduce variation in order to improve quality. At present, there is hardly any descriptions on the approaches used to implement SPC can be found in the literature. If descriptions are given, they often focus on the methodological aspects, i.e. SPC tools, Berger and Hart [13] and Chaudry and Higbie [14].

Wetherill and Brown [15] found that SPC sampling technique and quality control have been developed since the 1920s. Modern control chart and SPC developed by Walter A. Shewart were widely used during the 2nd World War in Britain and United States of America. Japanese companies had demonstrated that by applying SPC, a company would be able to minimize cost and as well as satisfying more customers.

SPC is a powerful problem-solving technique, which can be used for monitoring, controlling, analysing, managing and improving a process using statistical method [2]. The philosophy behind SPC concept is the output of a process can be brought into a state of statistical control by means of management and engineering intervention.

Swift et al. (1998) as quoted by Xu [16] have the opinion that the two main objectives of control chart are to monitor variation due to assignable causes and to take the appropriate corrective actions. SPC is a statistical technique commonly used to control and reduce process variation [10]. Variation reduction is a key aspect to improve product quality. There are two main causes of variation, assignable/special and common/chance causes [10; 17]. In other words, control chart is useful because it can be used to distinguish between assignable and common causes of variation in the process. In general, this variability arises from three sources: improperly adjusted machines, operator errors, or defective materials [18]. Basically, SPC comprise of seven statistical tools, such as: data gathering, histogram, Ishikawa diagram, Pareto analysis, control chart, scatter diagram and checklist. Meanwhile, Yang and Yang [19] viewed control charts as a process monitoring and control tool has received much attention both by public and private sectors. This fact is supported by Salzman [7], who contends that the variability of process can be monitored using a control chart by plotting a sequence of measured quality data along with the process control limits. Later, information gathered from the control chart can be used to calculate the process capability.

Alternatively, process capability can be calculated using three primary techniques, which comprise of histogram or probability plots, control charts and designed experiments [18]. In short, process capability study can be employed to predict the machine or tool performance. Having done that the machine or tool performance will then be used to determine whether the process has a low or high variability. It can also be used before or during the processes to detect incoming quality problems and eliminate the products that are out of specifications. There are two types of capability indices: C_p and C_{pk}, which are used for all critical variation followed by conducting statistical control test.

Generally, variability occurs in every production process. Therefore, quality level can be measured by using a process capability index, where C_p measures the spread of the specification relative to three-sigma process regardless of the location, while C_{pk} measures how well a given process is generating a specific characteristic with respect to specification limits. Thus, it reveals relationship of process spread and location with respect to the nearest design specification [20].

3 Advantages of SPC implementation

SPC implementation is important as it could improve process performance by reducing product variability and improves production efficiency by decreasing scrap and rework. According to Attaran [21], in their attempts to remain competitive, US business had embarked on TQM techniques such as SPC that leads to higher quality product by reducing: variability and defects; rework, failure, scrap, warranty claims and product recall costs, thus improving their overall business competitiveness [20].

Most of the production and quality costs that SPC aims to minimize such as rework, lost of sales and litigation are measurable. The success and failure in SPC implementation does not depend on company size or resources, but it relies on appropriate planning and immediate actions taken by workers with regards to problem solving. According to Benton [22] and Talbot [23], the advantages of implementing SPC could be categorise into the following categories, namely: maintain a desired degree of conformance to design; increase product quality; eliminate any unnecessary quality checks; reduce the percentage of defective parts purchased from vendors; reduce returns from customers; reduce scrap and rework rates; provide evidence of quality; enable trends to be spotted; ability to reduce costs and lead times. In other words, SPC implementation can also help to accomplish and attain a consistency of products that

meet customers' specifications and thus fulfil their expectations. In general, SPC can be used to monitor the natural variation of a process and minimize the deviation from a target value and thus play a major role in process improvement.

4 Methodology

Case study methodology was used in this research. It involves an in-depth investigation and appropriate when trying to answer the 'how' and 'why' questions of research [24]. Case study evidence may be in the form of qualitative or quantitative data or both, the combination of both data types is believed to be highly synergistic. This is in-line with the main research objective, that is to answer some of the 'how' and 'why' questions in SPC implementation. In this study, the main aim of case study methodology was to extract detailed information about how and why three Malaysian manufacturing companies had used SPC technique to evaluate their production machines capability and efficiency. The manufacturing companies involved in this study are producing: base plates (company A); printed circuit board (company B) and pill tablet (company C).

The authors had collected the qualitative data by conducting structured interviews on the company's production engineers and managers. The structured interviews questionnaire were consists of the company's background information, prerequisites for managing quality, general information of SPC awareness and its implementation in the company.

Meanwhile, quantitative data were collected by using an appropriate check sheet tailored to each company needs. During the data analysis, it is important to select right chart to interpret the data that have been gathered. Selection of chart will depend on data types such as variable or attribute characteristics. In this study, the X-bar chart and range chart were selected for performing the data analysis. The charts shall provide information whether the process is under control or out-of-control. Any factors that influence the process variation should be considered for elimination. Process control is vital to prove that action implemented is effective in solving process problem. The case study data gathered were later analysed using Minitab software and SQC-pack 2000.

In Company A, the quality characteristics selected for the study is base plate frame length. In Company A, 25 sub-groups of base plate frame length in millimetres with a sub-group size of 4 were collected.

In Company B, the quality characteristics selected for the study is percentage of positioning error for printed circuit board (PCB). In Company B, 25 sub-groups of printed circuit board (PCB) with a sub-group size of 2 were collected.

In Company C, the quality characteristics selected for the study is pill tablet hardness. In Company C, 25 sub-groups of pill tablet hardness with a sub-group size of 4 were collected.

5 Results and discussions

In this study, three manufacturing companies were selected to evaluate their production machine capabilities and efficiency. The outcomes study are summarised as follows:

To Company A, precision and accuracy in base plate milling process is critical in fulfilling their customer requirements. In Company A, high-speed CNC milling machines were evaluated to find out their capability and efficiency in fulfilling their customers' requirements. Data of base plate frame lengths machined by using the high-speed CNC milling machines were measured by a Coordinate Measuring Machine (CMM) at interval of one hour each.

Figure 1 shows X-bar chart and range chart that have been plotted using the data analysed by the Minitab software. The X-bar chart showed all the data with a sample size of four lies within the given upper and lower control limits. Note that, the upper specification limits (UCL) for the base plate frame length is 327.53 mm, lower specification limits (LCL) is 327.34 mm and X-bar value is 327.44. The R chart also shows that all the sub-groups mean values lies within the upper and lower control limits.

Statistically, from the data collected and analysed for the high-speed CNC milling machines showed that they are within statistical control limits and the process is under-control. Thus, it can be concluded that these base plate frame lengths are still under control and able to meet their customers specifications.

Meanwhile, Figure 2 shows a normal distribution with respect to the base plate frame lengths data collected in Company A. From the SQCpack 2000 software analysis, the maximum value, mean value and minimum value for frame lengths are 327.56mm, 327.44mm and 327.30mm respectively. The value for Standard deviation is 0.06mm and skewness value is negative 0.15. Three-sigma positive value is 327.63mm and three-sigma negative value is 327.25mm. Minimum value indicates that the value is intended to fall on left side of the graph. Process

capability value C_p and C_{pk} for machining base plate frame lengths were at 2.62 and 2.27 respectively. Thus, it can be conclude that the High speed CNC Milling Machine is very capable in producing consistent base plate frame lengths, since the value for process capability indexes were greater than one (>1).

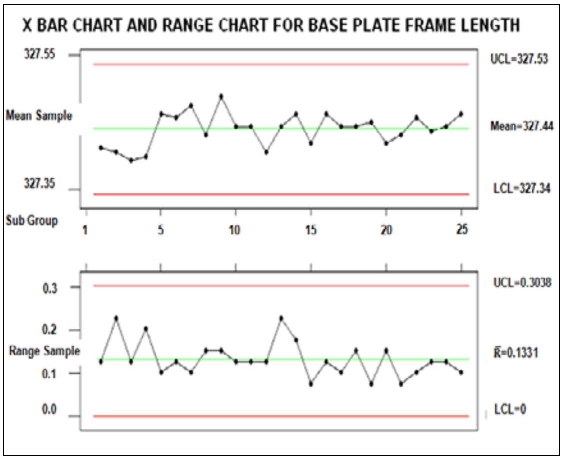

Figure 1: Analysis results of X-bar chart and range chart for base plate frame lengths

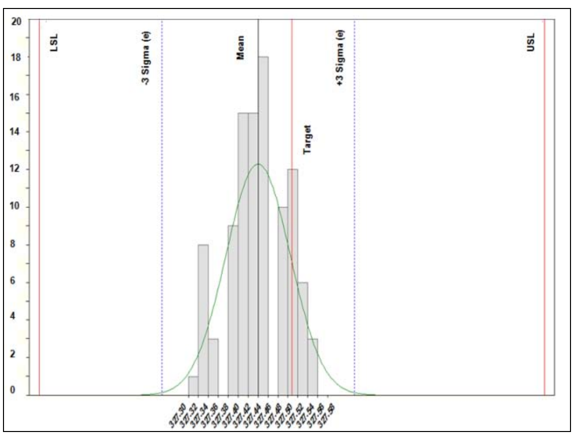

Figure 2: Analysis of process capability for the base plate frame length

In Company B, the defect rate for printed circuit board (PCB) was determined from percentage of positioning error data. In company B, High speed flexible stamping machines were used to evaluate the capability and efficiency of stamping process for producing and manufacturing PCB. During data collection process, a sample of percentage positioning error was taken from the high-speed flexible stamping machines at an interval of one minute. The data collected were later analysed by using the Minitab software and showed in Figure 3. Figure 3 shows X- bar chart and range chart that have been plotted using the 25 sub-group data and sample size of 2. Referring to Figure 3 the X-bar chart data from sub-groups 2,4,5,6,7,8 and 9 lies outside the lower control limit; meanwhile data from sub-groups 10,11,12,13 and 25 located outside the upper control limit. Statistically, the data collected and analysed for the high-speed flexible stamping machines showed there are 12 sub-groups data that lies outside the upper and lower control limits. In other words, the percentages of positioning error were not consistent due to the existence of subgroups averages that lies outside the upper and lower control limits. In other words, based on the X-bar and range chart drawn, it can be concluded that the percentage of positioning error for PCB manufacturing process was not very stable. Therefore, high-speed flexible stamping machines are not capable to manufacture PCB according to the given upper and lower control limits.

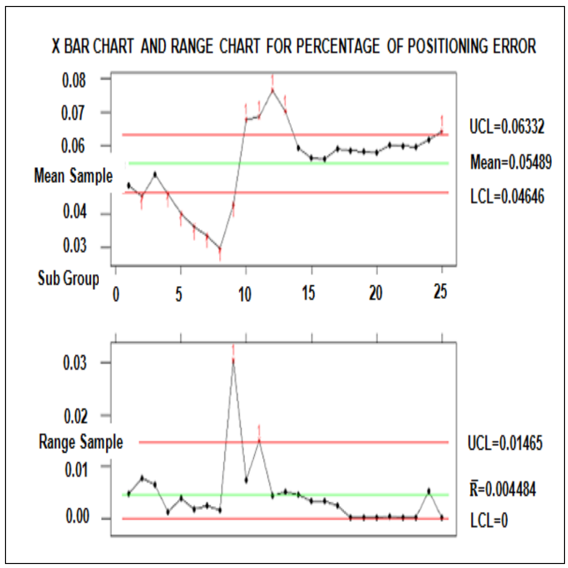

Figure 3: X-bar chart and range chart for percentage of positioning error

In Company B, the authors had provided five suggestions to ensure the PCB manufacturing process is under statistical control. First, computer programmers needs to be more careful and make sure that there is no mistake in coding that will cause PCB defect. Second, it is necessary to examine the quality and cleanliness of raw materials bought from suppliers. Third, the PCB feeder should be regularly

calibrated to ensure high-speed flexible stamping machine is capable of sensing the electronics components at the right location. Fourth, examine the machine head nozzle, if there is any solder blockage, clean it up. Fifth, to be able of producing high quality solders, the high-speed stamping the machine needs to be regularly calibrated. To do all these activities, the operators should be trained so that they have the skill to effectively maintain and run the high-speed flexible stamping machine with minimum PCB defect.

In Company C, pill tablet hardness is a very important quality characteristic or parameter in pill tablet manufacturing process to fulfil their customer requirements. In this case, pill tablet compression machines were evaluated to find out their capability and efficiency of manufacturing pill tablets hardness that fulfils company C customers' requirements. During the study, the authors saw many physical tests were conducted on pill tablets, they are: granulation test, thickness test, fragility test, and hardness test. In this case, hardness test was thoroughly performed because pill tablet hardness is a very important parameter in the manufacturing process. Figure 4 shows the X-bar chart and range chart for pill tablet hardness. On overall, both X-bar chart and R chart showed all the 25 sub-groups data and sample size of four lies within the given upper and lower control limits. Note that, the upper specification limits for pill hardness is 4.609 kg/cm^2 and lower specification limits is 3.059 kg/cm^2. Statistically, from the data collected and analysed for pill tablet hardness showed that they are within control limits. Thus, it can be concluded that these pill tablet compression machines are capable of manufacturing pill tablet hardness within the upper and lower control limits.

Figure 5 shows that data collected from the study forms a normal distribution. The maximum value, mean value and minimum value for pill tablet hardness are 5.30kg/cm^2, 3.83kg/cm^2 and 3.10kg/cm^2 respectively. The values for standard deviation and skewness are 0.53kg/cm^2 and 0.45 respectively. Three-sigma positive value is 5.38kg/cm^2 and three-sigma negative value is 2.28kg/cm^2. Minimum value indicates the value is on left side of the graph. Referring to Figure 4, X-bar for sub-groups 3, 4, 5, 6, 7, 8, 9 and 10 shows for eight consecutive points the values were hovering from above to below the mean values. In addition, sub-groups 20, 21, 22, 23, 24 and 25 shows for six consecutive points the values were hovering from below to above the mean values. In other words, this phenomenon shows the existence some form trends that require further in-depth investigation to find out the reasons why these trends had occurred. The process capability values C_p and C_{pk} for pill tablet compression machines were 1.16 and 0.93 respectively. Thus, it can be concluded from the case study, the pills tablet produced by the pill compression machine are still within the upper and lower control limits (i.e. UCL and LCL). However, if it is left unchecked it may result in producing pills tablet hardness that lies outside the control limits.

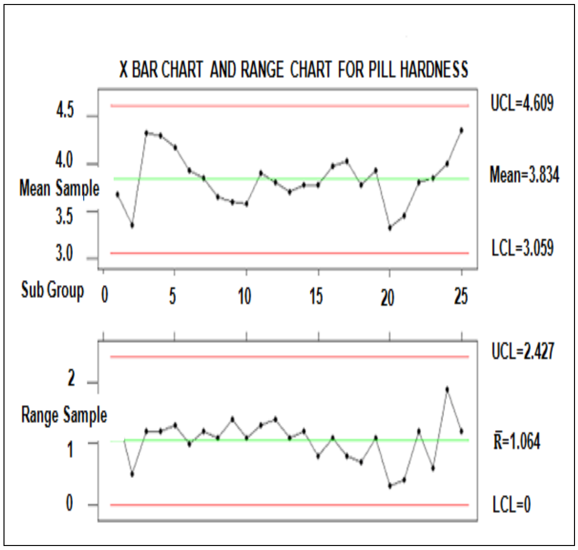

Figure 4: X-bar and range chart for pill hardness

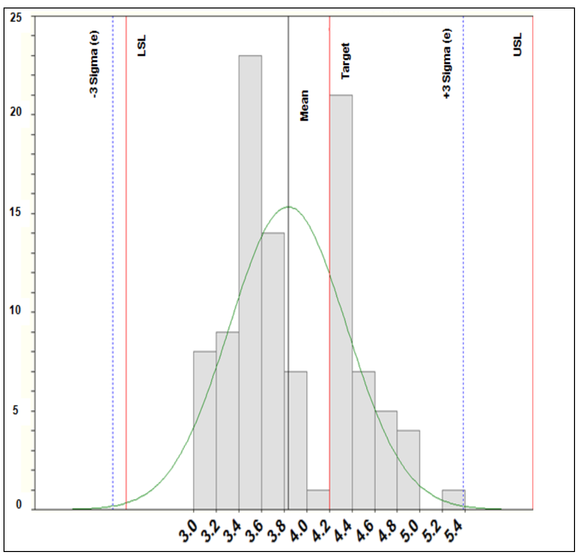

Figure 5: Analysis of process capability for pill hardness

Finally, it can be conclude that the pill compression machine is capable of producing consistent hardness for pill tablet, since it has a process capability (C_p) value of larger than 1 (C_p>1.0). In this case, the C_{pk} value of pill tablet compression machine is 0.93 (C_{pk} <1), which means that the process is not centred. Since the process is not centred, it needs to be closely monitored to see whether the up and down swing of the mean values are still within the stated control limits and thus avoiding the pill compression machine from producing pill tablets that do not conform to customers' specifications.

6 Conclusion

The case study conducted in the three companies had showed the importance of statistical process control (SPC) for monitoring and ensuring the products produced are able to satisfy customers' needs and requirements. All the three case study companies had used SPC as a quality control and improvement tool in their products manufacturing process. In this study, SPC technique was used to evaluate machines' capability (C_p) and process centring (C_{pk}) of manufacturing process involved in manufacturing and fabricating products.

In Company A, the base plate manufacturing process is in statistical control, variations in the base plate mean values are very small. This shows the process is very stable and thus able to produce consistent base plate lengths. In other words, high-speed CNC milling machines used in the manufacturing process are very capable of producing consistent base plate lengths. In Company B, the authors did not calculate the process capability values because prior to this case study Company's B top management had assumed the PCB manufacturing process is in-control. However, the result from the case study shows the PCB manufacturing process is out of control because the mean percentage of many subgroups samples for positioning error data lies outside the upper and lower control limits (UCL and LCL). To overcome this problem, the authors had suggested to Company B top management to carry out further investigations on the PCB manufacturing process to find out the root causes and take necessary actions to solve and rectify the problem. In Company C, the pill tablet compression machine is under statistical control and able to manufacture pills tablet within the stated control limits values (UCL and LCL).

Application of SPC in product manufacturing process is very important because it helps to provide engineers and company management on the quality status of the product manufactured, whether it meets customer specifications or not. This paper provides an insight of SPC applications and implementations in Malaysian manufacturing companies.

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